OPTIMIZATION OF CABLES IN A SOLAR POWER PLANT USING GENETIC ALGORITHMS

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ABSTRACT

The design of a photovoltaic solar plant installed in consists of sizing the equipment, protection components, defining the best arrangement of these components within the available area as it directly affects the length of conductors used. Defining the best placement to allocate the electrical components configures a optimization problem with combinations, due the several number of possible design in the solar power plant. Thus, this article proposes an analysis of two forms of execution of solar projects presenting the electrical losses in cabling and using the genetic algorithm implemented in the Evolutionary Mode of the spreadsheet system on Excel to find the best arrangement of the components, later performing a comparison between the electrical losses of each layout. The results show that the positioning found by the genetic algorithm was able to reduce the electrical losses of the solar system by 60%, this new proposed arrangement was able to increase 6MWh year of generated electrical energy, showing that the most efficient solution is to allocate the components of the system at the central point in relation to the modules displaced in relation to the free area between panel and meter, since the area is occupied with the panels fixed to the ground.

KEYWORDS: *Optimization, genetic algorithms; cable losses; solar power plants; renewable energy*

I. INTRODUCTION

1.1 Introduction to photovoltaic systems.

Solar energy has grown exponentially in the world, and Brazil would be no different, with the installed power of this renewable and clean energy doubling year after year, that installation has become increasingly common, driven by consumers who want to generate their own energy in a healthy way carrying out projects in their homes, markets and even in large areas of land that were previously empty and unused, this areas are now being used by solar panels to produce electricity, this new application is used to strengthen the energy source of the country, increasing the sustainability and security of electricity supply in Brazil. Attracting investments of more than BRL 22.8 billion in large, medium and small plants, it represents today a growth of almost 50% compared to 2012 to 2020. Without a doubt, solar energy has brought great representation and importance in the country [1].

A solar power plant of any size needs a set of components. The photovoltaic module is responsible for capturing the irradiation of sunlight and transforming this energy into electricity, this component is also commonly called as solar panel, which is the heart of the entire system. The responsibility of inverters is to transform the electricity created by the solar modules which are in direct current into alternating current, also, the inverters have protections inside, such as the function of turning off the system in case of failure in the network grid, this component can be considered as a brain of the system. For the compatibility between the voltage of the network grid and the inverters, the transformers are used, without it would be impossible to make the connection because of the electrical parameters. The conductors are used to make the connections between the components, being extremely important the correct sizing to guarantee the security of the systems [2].

There are several points of loss in a photovoltaic system, for example, module transformation losses, shading losses, inverter efficiency losses and also conductor losses caused by the joule effect, which this is the focus of the study [4] . So minimizing cabling losses is a process to maximize the efficiency of a system and consequently improve the generation of electrical energy, these losses being a complex optimization challenge to find the ideal point due to the various possible scenarios within an area in which a solar plant will be installed.

1.2 Computational intelligence.

Evolutionary computation consists of computational methods based on biological theories to solve problems. In human biology, evolution always constantly solves optimization problems by stimulating changes in living beings to become more adapted to the environment. The genetic algorithm is centered on Charles Darwin, about the evolution theory, which consider the selection as natural process of the fitter individuals survival [5-6].

The evolutionary method is a native solution tool for the Excel spreadsheet program that is based on the genetic algorithm for solving complex nonlinear problems, just insert the problem parameters, with the constraints and the objective function. In order to have precision in the solution of the problem it is necessary that correct and consistent information be inserted. The genetic algorithm executes the functions according to operators, initializes the population of chromosomes, after carrying out the evaluation of each chromosome of the population, creates new chromosomes of the current population, performing the crossover and mutation operator and ends, if the final criterion is reached, otherwise, it restarts in search of the optimal solution with the new population [7-8].

There are other optimization methods like Particle Swarm Optimization where it is a heuristic algorithm, that looks on the social behavior of birds group aiming to search for the best solution in a search field, through the comunication with individuals to determinate which trajectory is going to be choose in the space. It has been applied in optimization of electrical problems, such as the sizing of power distribution systems. [9]

Another widely used method is the Artificial Bee Colony Inspired by the behavior of bee colonies, this method is composed of employed, observant and exploiting bees. The employed bees look for food sources, the observers assess the quality of the sources, and the explorers look for new solutions. ABC has been applied in optimization of problems such as system sizing.[10]

There are several optimization methods, such as Lightning Search Optimization, which arose through the observation of electrical discharges, well used to determine parameters of electrical networks, and the Ant Lion Optimizer, which arose from the observation of the behavior of ants and lions, where it is well used in the planning of distribution network expansion. [11-12]

The genetic algorithm was chosen to conduct this study because it allows to comprehensively explore the search space of these parameters (X and Y coordinates for distance definitions), seeking optimal solutions or close to the global optimum. Another advantage of the genetic algorithm is that it works with several optimal solution points, multimodal, important when dealing with driver losses, where, for example, Particle Swarm Optimization and the Artificial Bee Colony, can get stuck when finding a great location. Therefore, they are very optimized in optimization problems related to renewable energies. [13]

1.3 Related Work.

Most of the studies already carried out use optimization to increase the energy conversion efficiency of the technology used using the genetic algorithm to find the best optimal solution to reduce losses. Authors in [14] carried out a work on wind farms to optimize facility layouts, this is one of the methods to increase the energy production of wind farm investigating the wind turbine hub on different heights on compact wind power plant by evaluating the generated output power. Three different wind conditions are analyzed using a genetic algorithm implemented in MATLAB, where the results show that the wind power increases even with the hub are in different heights, even if the number of turbines is the same. Different cost models are also taken into account in the analysis, and the results show that wind turbines hub with different heights can also improve the cost per unit of power of a wind farm. Finally, a study is carried out in a large wind farm with commercial wind turbines to prove the benefits of modifying the height of the hub in a more realistic way to satisfy the wind conditions using genetic algorithm to improve energy production.

Likewise, the authors in [15] carried out a study to optimize energy production in wind farms by modifying the positioning of the turbines, but the focus of this study is the improvement of the conventional genetic algorithm applied in the positioning of the turbines. First, the efficiency of all turbines is verified, thus defining which are the best for energy production and finding the others whose production is impaired. Therefore, the solution starts by identifying the worst helix of the plant by conventional genetic algorithm and applying a modified genetic code and then performing a new optimized configuration in the positioning, the authors disclose the codes used for future studies and work.

The study carried out by the authors in [16] is about photovoltaic systems with charge storage, showing that this type of system brings flexibility to adjust the necessary demand, but also makes it challenging to use them with maximum performance, thus being the objective of the work. The impacts of batteries and thermal storage technologies to supply the necessary demand in the load region were investigated. In the first proposed strategy, the author found good technical and sustainable progress, but little economically attractive and low performance to supply a negative demand. After manual attempts, a genetic algorithm-based code was implemented to obtain the solution considering economic, technical and environmental performance factors, optimizing the layout and operation of the system to maximize results, showing that costs were reduced by 37.46% when compared to the traditional case and 38.32% when compared to the multiple optimization, respectively.

One of the challenges in India is the supply of electricity, the author in [17] highlights three fundamental objectives, the first to minimize the demand needed to supply with the solar power plants production, the second objective is to minimize the unit cost of this generation and finally, to minimize transmission and distribution losses to serve the cities, thus showing a complex optimization problem with multi variables, where the genetic algorithm is chosen to find a solution close to the optimal one. The location of the best plant for India was found with the optimization and presented an improvement of capacity utilization of 18%, showing that the requirements were met. In [18] was proposed to use the genetic algorithm to control and improve the power flow of smart grids, using as variables of the system the cost of solar and wind generation, operational costs, being carried out a comparison between the genetic algorithm method and the method with existing algorithms and presenting effective results were obtained with the proposed method.

The author in [19] uses the genetic algorithm to maximize the energy production and make the solar cells more efficient, to carry out this verification and to find the best point between the doping section and the configuration of the thickness of the cell making a comparison between the market cell and the optimized configuration in MATLAB, the results showed a significant conversion improvement of 29.7% considering parameters of self-generation rate, external and internal quantum efficiency. In [20] the genetic algorithm is used to increase energy conversion and minimize the cost of photovoltaic inverters production, this optimization has as variables the electronic components and the ripple of output current, the result found showed that it makes this project easier the production and improve the launch time of the inverter in the market.

In [21], the authors proposed to redesign the medium voltage distribution network of wind farms using genetic algorithm to minimize operational and construction cost and reduce conductor losses using various methods. The results show that depending on the method used, the system may not have an economic advantage and may not be efficient. The study carried out by [22] used the genetic algorithm to optimize the performance of an airfoil of a wind turbine, obtaining the best result among the six models.

A hybrid renewable energy system (HRES) has many variables and becomes a non-linear problem, so the authors in [23] proposed an optimization code with the function of minimizing construction and daily cost and minimizing which energy shortages, where it showed that the optimized system showed satisfactory results. In [24] a similar work that use ALO (Ant Lion Optimizer) as optimization methods to optimize the generation control of energy, the results showed an improvement in the cost of the connected grid network by 4.70% of the system.

The authors in [25 – 31] carried out their studies with clean and hybrid energy to improve efficiency and maximize generations by applying it in different case studies around the world, using other optimization methods, in particular, swarm optimization technique. The results showed advances in comparisons with the traditional methods that were used.

We searched the database on Scielo and Scopus using the keywords "cable loss, solar energy, optimization" to find direct studies in this field, but no related or similar studies were found.

1.4 Proposals, News and Contributions.

The goal of this work is to optimize an engineering design of a solar power plant proposed to meet the consumption of electricity in an industry by injecting generation through the electrical grid, showing two models of installations most used in Brazil, where the first execution layout put the inverters below the photovoltaic modules and the other considers that the inverters are allocated close to the electricity meter of the energy company. And then use the genetic algorithm to find to best solution to minimize the cable losses.

Unlike the other studies presented that use the genetic algorithm to optimize wind turbines, plant location in external distribution network, maximize the efficiency of a solar cell and optimize the internal distribution network of wind farms, this study brings innovation applied directly on the main components of a photovoltaic system working on the redistribution of internal circuits to reduce the distance between conductors. Searching for existing works on the Scopus platform and on the Web of Science platform, using the keywords Solar Energy, Genetic Algorithm, Solar Power Plant and Optimization, and no file was found dealing with same subject of this work.

Besides, photovoltaic plants have high complexity in the definition of the layout because they can vary according to the particularities of the terrain, for example, n rows in horizontal, n rows in vertical, n spacing between these rows, n points of connection to the grid, thus hindering finding the best places to allocate your alternating current components efficiently. This work novelty is to find the best positioning in order to optimize the losses in the electrical conductors using the genetic algorithm in a safe way, which any reader can apply in their future analyses, thus maximizing the energy production by reducing the losses.

The equations (1-4) show the fuction we are going to use for optimization to minimize to cable loss

$$Pcc = Pst1 + Pst2 + \cdots Pstn \tag{1}$$

$$Pca = Piv1 + Piv2 + \cdots Pivn \tag{2}$$

$$Pmt = Ptf1 + Ptf2 + \cdots Ptfn \tag{3}$$

$$Ptot = Pcc + Pca + Pmt \tag{4}$$

Where,

Pcc = cable loss in each strings bounded to equivale inverter (kW);

Pca = cable loss in each inverter bounded to equivale transformer (kW);

Pmt = cable loss in each transformer bounded to equivale energy meter (kW);

Pst = cable loss in strings of panels (kW);

Pinv = cable loss in the way of inverter to transformer (kW);

Ptf = cable loss in the way of transformer to energy meter (kW);

This study is a direct application of the genetic algorithm implemented in the Excel spreadsheet system, a worldwide used and easily accessible program, making easy this article can be used all over the world. It is not the scope of this work to develop the genetic algorithm itself.

After optimizing the distribution of the solar system components, it is verified that the best place is to allocate the inverters and the transformer in the central point of the photovoltaic system, but to move it to a place where it will not be taken with the installation of the modules. Showing that distributing energy through a system with high voltage is better to minimize losses.

Adding that, the results minimize in 60% and 50% with the case studies performed compared to the positioning obtained through the genetic algorithm. Showing that computational intelligence can maximize solar energy by reducing losses.

The study manages to show an increase in the intended electricity generation of 6MWh year compared to the proposed initial positioning and 2MWh year to the second case studied, this performance will be reflected throughout the useful life of the photovoltaic system, which lasts on average 25 years.

The structure of this work is presented as follows, introduction where the main objective is to introduce the concepts, review the literature and present the study. Subsequently, the material and methods section explains the methodology applied, how to replicate the study, and understanding of the case, the results and discussions section, presents what is considered and the comparisons made in the work, the conclusion chapter summarizes the main findings of the article, finally, the bibliographic references used and the biography of the authors.

II. MATERIALS AND METHODS

The methodology used to approach this work is carried out throughout the chapter, as well as its theoretical foundation, first the project is shown to which the case studies will be established for knowledge, later it is shown how its optimization is carried out and finally the making comparisons between the cases studied. To validate the losses and performance of the solar power plant was used the PVsyst program [32].

We can simplify the methodology for this work as follows: See Figure 1 to flowchart.

A- Preliminary presentation of the study meeting the proposed need to define the layout.

B- Case 1, installation of the components of the plant in a direct way putting the inverter behide the solar panels as designer decision, showing the calculations and mathematical foundations to define the losses, using the Pvsyst to evidence the annual energy production and validate the electrical losses in cabling by section.

C- Case 2, installation of the components of the solar plant directly close to the connection point with the electricity distributor decision of designer, in the same way using Pvsyst to evidence the annual energy production and electrical losses in cabling per section.

D- Application of the genetic algorithm, demonstrating how to perform the configuration of the applied optimization, which was used as variable and constants. Pvsyst is used to perform the measurement of annual energy production and conductor losses to validate the results.

E- After presenting the comparative results, we showed that the genetic algorithm was able to find a better solution between the cases demonstrated and the discussions.

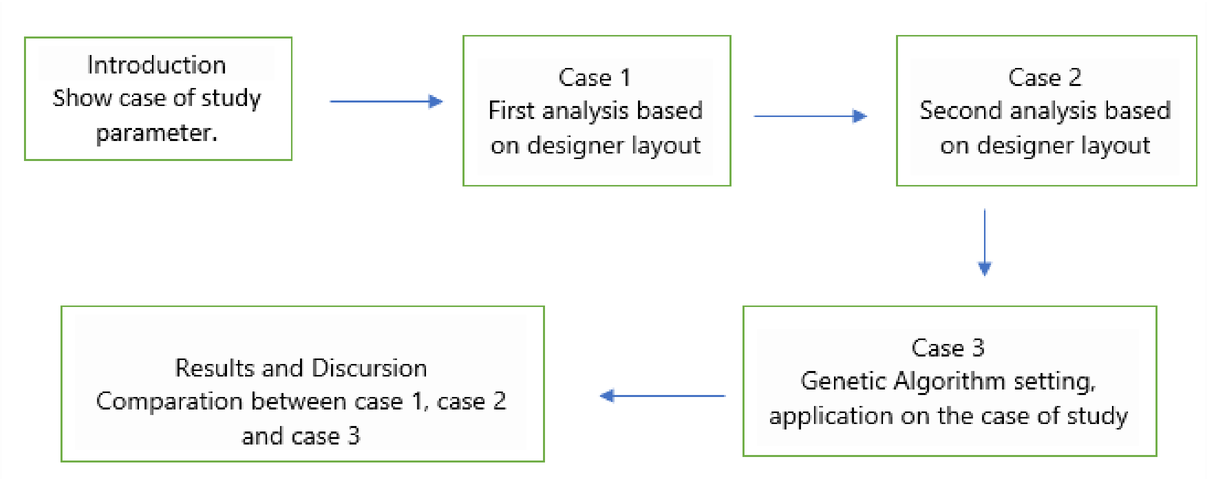

Figure 1. Guiding for paper

Note that premises applied on this study is the same for Case 1, Case 2 and Case 3 to remain the confiability of the paper and the results. The premises is shown in Case 3 section and is the position of panels and energy meter, and the variable of the paper is the position of inverter and transformer.

The premises is better explained in Case 3 because it is necessary to set the distances between the way of solar power project to use on evolutionary mode of excel to apply genetic algorithms. In the others case, we already give the distance and results, but can be use the premises to calculate the distance for each case.

2.1 Introduction.

The design of the Zemildo Peres 742.5 kWp solar power plant was a study carried out in São Paulo, Brazil, with localization -46.6363, -23.5470, on a plot of land 100m long and 250m wide available for the execution of the project, aiming to serve a factory 200km from the installation site of the plant , thus using the distribution network to transport the energy generated and reduce consumption in the factory's electricity bill. According to Table 1, the preliminary data of the project can be verified.

Table 1: Preliminary data from the solar plant.

	Data
Number of modules	1350
Manufacturer/model	ERA SOLAR
Panel power	550W
Number of inverters	5
Manufacturer/model	Goodwe/GW120K-HT
Inverter power	120kW
Expected Energy	1110 MWh/year

The solar panel used in this paper has high quality produced by the chinese manufacturer ERA Solar, having the following technical parameters with operating voltage and current at nominal conditions of 41.96V and 13.11A, having a high energy conversion efficiency of 21.3%. Likewise, the inverters produced by the manufacturer Goodwe serve numerous plants around the world with their nominal characteristics of 173.2A of nominal current output and 400V of output voltage.

2.2 Case 1:.

In this first study carried out, it was considered that the best positioning of the inverters would be below the photovoltaic modules to optimize the execution of the work, and the power transformer would be installed close to the energy input of the distributor at the connection point . See Figure 2, according to the caption, the starting and ending point of each module is observed, and between this space is the physical installation of the modules.

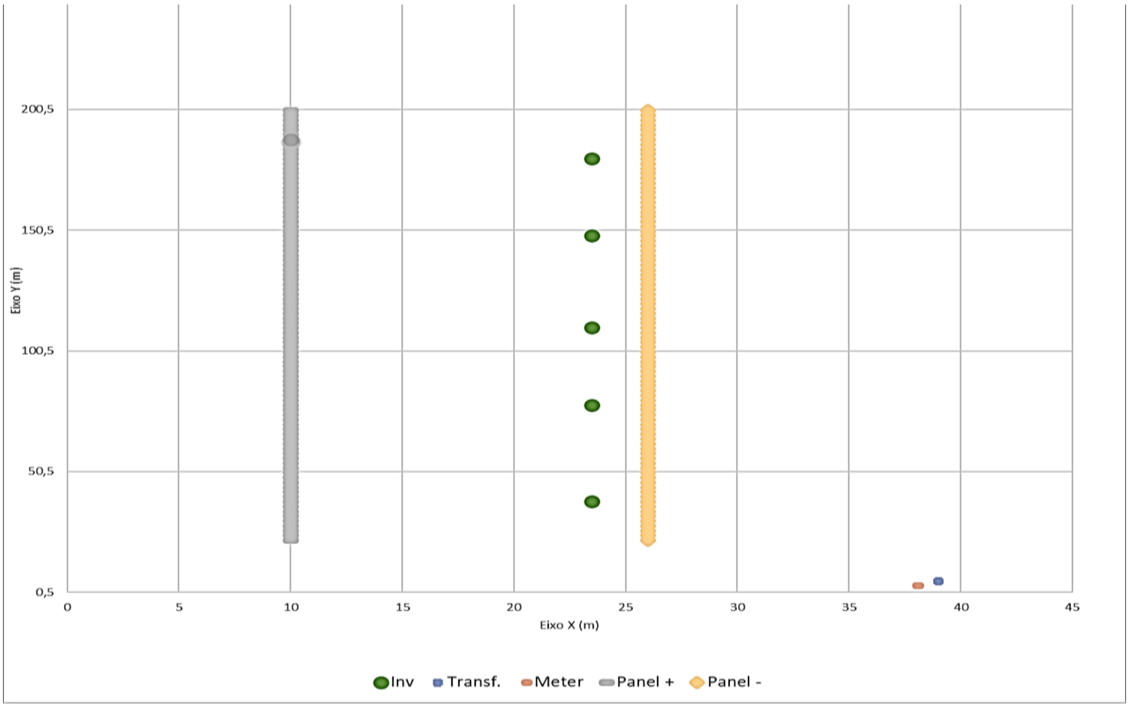

Figure 2: Proposed initial positioning of the plant with inverter allocated to the modules

This type of execution is very common, as it is practical for the execution of the work, and easy to manage the photovoltaic module arrangements. Configuration details between modules and inverter are shown in Table 2.

Table 2: Solar system configuration case 1.

	Data
Number of strings	90
String modules	15
Solar cable	6mm²
Average distance between module and inverter	13.3m
Ohmic losses	0.54kW
Percentage ohmic losses	0.07%

The electrical losses related to the section between the solar panel and the connection of the inverters can be calculated according to equations (5) and (6). As photovoltaic modules have a large variation in their operating current due to irradiation and other parameters, a factor of utilization of 60% is considered [33].

$$P = 2 * R * I^2 * D \ * 0,6 * Nst \quad (5)$$

$$P\ (\%) = Pst * 100/Pfv \quad (6)$$

Where,

P = Electrical losses (W)

R = Resistance of the 6mm² solar conductor set to 0.0034 (Ω /m).

I = Module operating current in NOCT set at 10.55 (A)

D = Average distance of the section (m)

Pfv = Total power of the plant modules

Nst = Number of strings

In the same way, the electrical losses of alternating current components, their connection between the inverter and the transformer, are calculated. See Table 3.

Table 3: Inverter output configuration case 1.

	Data
Average distance between inverters and transformer	107.4m
Inverter output current	173.2A
Inverter output cable	$120mm^2$
Ohmic losses	6.10 kW
Percentage ohmic losses	0.82%

The output of the inverters works on alternating current, the factory and operating data are obtained from the equipment's technical sheet, therefore, the calculation of electrical losses, follows equation (7), below.

$$P1 = 3 * R * I^2 * D \quad (7)$$

P1 = Three-phase electrical losses (W)

R = Conductor resistance specified and fixed at 0.00021(Ω /m)

I = Rated inverter output current (A)

D = Average distance of the section (m)

Likewise, percentage losses are calculated according to equation (6).

The particularity of a photovoltaic system lies in the fact that the inverter does not maintain a constant current during operation due to the variation in radiation that the module suffers during the day. Thus, we will adjust the losses according to equation 4 [28].

$$P = P1 * 0.6 * N \quad (8)$$

Where,

P = electrical losses for solar system (W)

P1= Electrical losses in alternating current for three-phase circuit (W)

N = Number of inverters

Exist an unbalance between the output voltage of the inverters and the electricity distribution network, a transformer is used, among the transformers, the voltage parameter is 15kV, which is equivalent to the distribution connection network and its output according to the inverter working voltage in 400V. Table 4 presents the parameters of this equipment.

Table 4: Configuration of transformers case 1.

	Data
Average distance between transformer and meter	2 m
Current at the output of the transformer	866A
Current at the input of the transformer	23.09A
Connection cable	$10mm^2$
Ohmic losses	0.0047 kW
Percentage ohmic losses	0.00%

Likewise, the operation in an alternating current circuit uses Equation (7) and (8) and the resistance of the medium voltage cable is 0.0024 (Ω /m), but it is necessary to adjust the working current ratio of the transformer at the input of this component . Equation (9) is used.

$$Ie = Vs * Is/Ve \quad (9)$$

Where,

Ie = Input current (A)

Vs = Inverter working voltage (V)

Is = Total inverter current, configured with transformer output current (A)

Ve = Grid connection voltage at 15,000V

2.3 Case 2.

The second study respected the same photovoltaic system defined in Table 1, but the positioning of the inverters would be close to the transformer, that are close to the measurement point, as this configuration reduces alternating current losses by maximizing the length of the solar cable, consequently maximizing its losses in direct current and minimizing the losses in alternating current. All generation and loss simulations were carried out with the help of Pvsyst for validation of electrical losses and generation simulation of the year, the distance between conductors and their parameters were entered manually in the software as shown in the study.

This type of installation has become common today because it is considered more efficient, making the system produce more energy, as in direct current the arrangements carry small electric current and work with a voltage of approximately 1000V per arrangement with a current of approximately 11A. Figure 3 illustrates the positioning of the components on the ground, according to the caption, the starting and ending point of each module can be seen, and between this space is the physical installation of the modules.

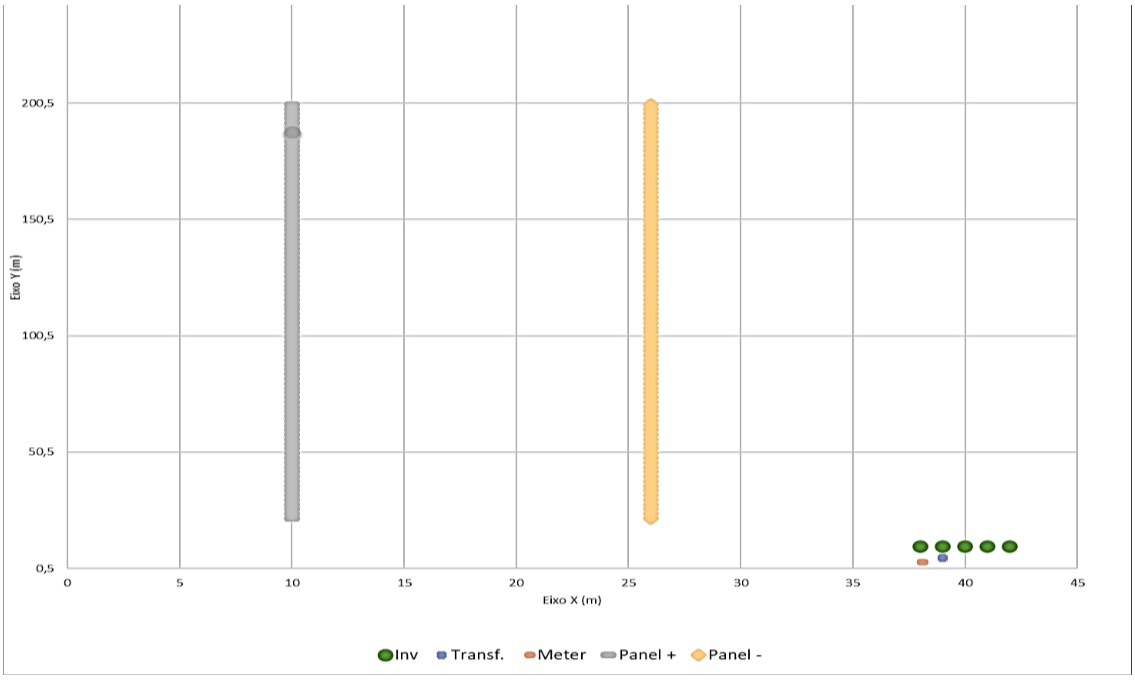

Figure 3: Proposed initial plant placement with inverters placed next to each other in measurement

Tables 5,6,7 show the relative losses in the proposed configuration that proved to be more efficient in relation to the first proposed model.

Table 5: Solar system configuration case 2.

	Data
Number of strings	90
String modules	15
Solar cable	6mm²
Average distance between module and inverter	105m
Ohmic losses	4.28 kW
Percentage ohmic losses	0.58%

Table 6: Inverter output configuration case 2.

	Data
Average distance between inverters and transformer	5.2m
Inverter output current	173.2A
Inverter output cable	120mm²
Ohmic losses	0.29 kW
Percentage ohmic losses	0.04%

Table 7: Transformer configuration case 2.

	Data
Average distance between transformer and meter	2 m
Current at the output of the transformer	866A
Current at the input of the transformer	23.09A
Connection cable	10mm²
Ohmic losses	0.0047 kW
Percentage ohmic losses	0.00%

Table 8 performs a comparison of losses and generation between the previously proposed models, where the second comparison proved to be more productive. Considering that a solar system will work for an average of 25 years, reflecting this energy considerably. A gain of 4 MWh per year can be seen in system 2 compared to the previous system.

Table 8: Comparison between case 1 and 2.

	Case 1	Case 2
Estimated annual generation	1111	1115
Losses between module and inverter (%)	0.07	0.58
Losses between inverter and transformer (%)	0.82	0.04
Losses between transformer and meter (%)	0.00	0.00
Total losses (%)	0.89	0.62

2.4 Application of Genetic Algorithm for optimization.

Computational power helps us simplify tasks that have become exhausting and impossible in everyday life, and with great sensitivity to errors. Excel spreadsheets have great prominence within the segment and have the native Solver on their platform, which works with the genetic algorithm to solve highly complex problems, without the need to create a programmable code.

It can be noticed in this study that the layout of a photovoltaic plant is set by the designer, and the biggest problem is to find a solution that minimizes the electrical losses in the conductors due to the large space of execution of the work, and the positioning problem directly influences in the distance, which consequently, at greater distances, is less efficient, consequently greater loss in the electric power cables, forming an optimization problem.

In this way, we apply the genetic algorithm in the Solver to solve this proposed problem and verify if we can find a better solution, and / or, validate one of the case studies 1 and 2 as an optimal place to position the inverters and transformer within an the area to operate the solar plant.

At this point we will describe all the path taken to arrive at the optimized solution so that any reader can apply it in future studies for any solar plant.

Initially, Excel configuration is carried out by activating the Solver mode that is located in the tools tab, accessing the menu Data and clicking in Solver button, thus, entering in the configuration.The genetic algorithm is native in Evolutionary Mode, where it must be chosen to activate this form of solution. Below are the settings made in evolutionary mode to apply the genetic algorithm, remembering that the computational effort is important, it depends on the machine that will run the problem, it may be necessary to modify the patterns to achieve perfect convergence.

1- Convergence: 0.000000001

2- Mutation rate set to 0.0015

3- Population size set to 950

4- Time of convergence with no solution at 1200

5- The variables will be the X,Y positioning of the inverters and transformers defined later.

6- The objective will be to obtain the smallest losses.

7- The limitations were defined as the distance between the connection meter of the grind and the photovoltaic modules.

After the settings of the Excel spreadsheet system with the Solver mode duly prepared to carry out the proposed optimization, it remains to define its variables and calculation premises datas.

The variables of our system are the positioning of the X,Y coordinates of the five proposed inverters and the transformer connecting to the electrical network.

The premises are defined as constants has been presented in this study that we will use for calculations, such as inverter technical specifications, module technical specifications, conductor resistance, grid connection voltage.

Tables 9 and 10 show the premisses and variables that are used to build the spreadsheet in Excel. The position show in Table 9 was defined by the designer considering the space that have to be use to do the solar ground project as presented in introduction. Note that the Table 9 present the position the positive pole of the solar cable, and the negative positive will be the same Y coordinate, but with X position on 26. The space between the positivo pole and negative pole is where the solar panels will be placed.

Table 9: Positioning of modules with premisses of case studies

Modules (X,Y) Positive pole of the solar cable. of the solar cable. This module configuration is applied for all cases 1,2, 3.					
x	y	x	y	x	y
10	200	10	140	10	80
10	198	10	138	10	78
10	196	10	136	10	76
10	194	10	134	10	74
10	192	10	132	10	72
10	190	10	130	10	70
10	188	10	128	10	68
10	186	10	126	10	66
10	184	10	124	10	64
10	182	10	122	10	62
10	180	10	120	10	60
10	178	10	118	10	58
10	176	10	116	10	56
10	174	10	114	10	54
10	172	10	112	10	52
10	170	10	110	10	50
10	168	10	108	10	48
10	166	10	106	10	46
10	164	10	104	10	44
10	162	10	102	10	42

10	160	10	100	10	40
10	158	10	98	10	38
10	156	10	96	10	36
10	154	10	94	10	34
10	152	10	92	10	32
10	150	10	90	10	30
10	148	10	88	10	28
10	146	10	86	10	26
10	144	10	84	10	24
10	142	10	82	10	22

Table 10: Positioning of AC components, inverters and transformers as variables and the meter as a premise

Position	Inverter 1	Inverter 2	Inverter 3	Inverter 4	Inverter 5	Transformer	Subway	Case
Position X	23.5	23.5	23.5	23.5	23.5	39	38	1
Y position	38	78	110	148	180	5	3.2	1
Position X	38	39	40	41	42	40	40	two
Y position	10	10	10	10	10	5	3	two

Tables 11 and 12 present the premises that are used for the replication of the case study, these are constants for carrying out mathematical calculations.

Table 11: Premises for calculation

	Module	Inverter
Operating current (A)	10.55	173.2
Operating voltage (V)	41.96	400

Table 12: Conductor resistance premises

	Resistance (Ω /m)
6mm² solar cable	0.0034
120mm² cable 1kV	0.00021
10mm² 15kV cable	0.0024

It is extremely important that when performing the procedure in Excel, the calculation of losses is calculated through Excel equations using basic functions such as addition, subtraction and division, because when applying the optimization solution, the data could be viewed in real time. An Excel file is available for further understanding and further use by other readers at: https://github.com/eluan1/Hindawi_excel.git

After defining all the variables, premises and calculations in the Excel spreadsheet system, the genetic algorithm is applied. Optimization takes about 2 hours to solve and to find the best solution.

The genetic algorithm will confirm positioning of the inverters and transformer at the same point, so it is considered to have a distance between inverters of 4m in Y and transformer in X of 6m for the layout after the results solution.

Figure 3 shows the new positioning of the alternating current components found through the genetic algorithm using inverters and transformer as variables, where we can observe that the inverters and the transformer were allocated to the center of the module according to the limitations set before In this way, according to the Figure 4, the starting and ending point of each module is observed, and between this space is the physical installation of the modules.

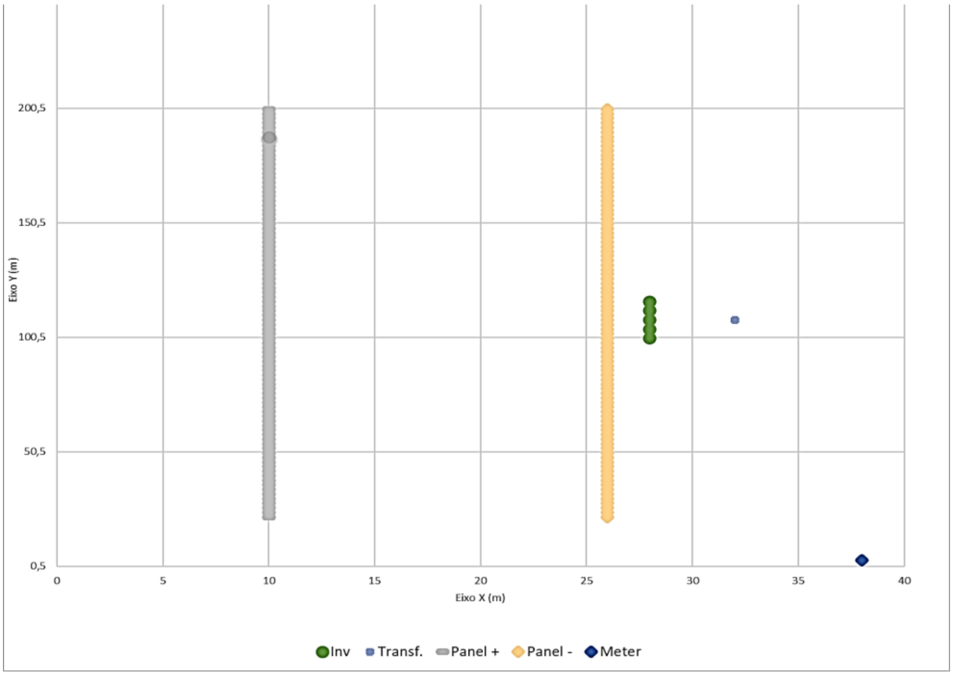

Figure 4: Positioning proposed by the genetic algorithm

Table 13 shows the distances and losses calculated for each stretch from the proposed system found by the Excel genetic algorithm.

Table 13: System losses projected by the genetic algorithm

	Modules - Inverter	Inverter - Transf.	Transfer - Meter
Average Distance (m)	43	6.64	105
Losses (kW)	1.76	0.40	0.24
Percentage losses (%)	0.24	0.05	0.03

To ensure the reliability of this study, the Pvsyst program was performed to validate the results of losses presented by the distance and the conductors as defined. The PVsyst software was used to perform the annual generation simulation showing an annual production of 1117 MWh. Figure 4 shows the single-line electrical scheme used and proposed for the three case studies, thus highlighting the electrical arrangement used.

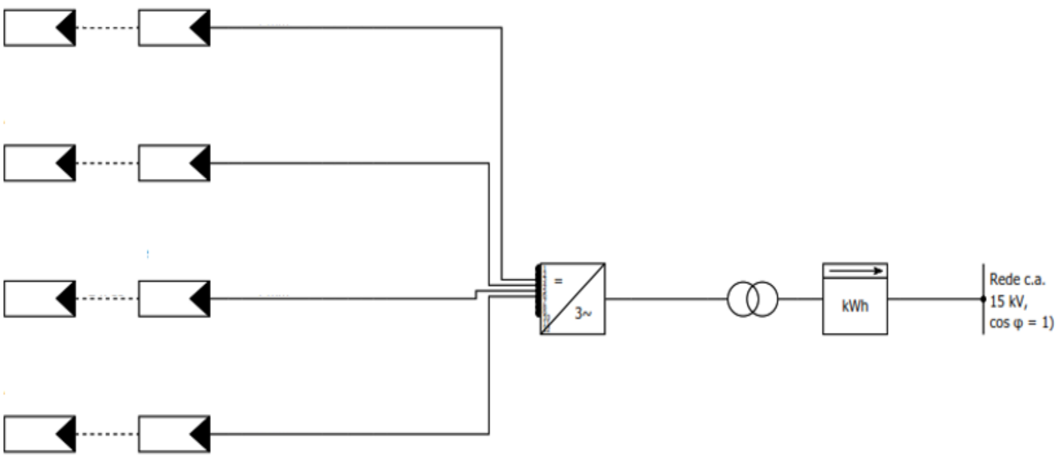

Figure 4: Single-line diagram illustrating the electrical connection

It was found that the optimized system managed to produce more energy to meet this project, as it managed to minimize electrical losses, the project has an expected energy output of 1110 MWh year and the system that was simulated generate 1117 MWh year.

The optimized system showed that the components, inverters and transformer, should be arranged in a physical location that coincides with the center of the displaced modules installation area.

Furthermore, the genetic algorithm showed high performance in reducing the electrical losses in the cabling just by solving the multiple positioning problem in the grounded mount solar plant. Where, in comparison with case 1, 2 and 3, the last case improved the losses of 60% in relation to the first case and 50% in relation to the second case.

In this way, just looking at the minimized electrical losses, the production of electrical energy was maximized, meeting the expectations of the project, where the project could take two directions, such as reducing the size of the plant or taking advantage of excess production to carry out a factory expansion.

III. RESULTS AND DISCUSSION

3.1 Results.

In the previous chapter, two case studies carried out by an engineering designer were presented, showing two methods of installing photovoltaic plants used worldwide, where the first places the inverters below the photovoltaic modules and the transformer close to the connection point of the electricity grid meter, and the second method places the inverters and transformer at the same point close to the connection to the eletric energy company. The losses in the conductors of each section are shown in Table 8.

The presentation of the multiposition optimization problem of each component of the plant was shown and configured, with five inverters and one transformer, the genetic algorithm is used to solve the problem. Table 13 shows the results of electrical losses produced by case 3, optimized system, and a comparison with case studies 1 and 2.

Table 13: Comparative table between the proposed cases 1,2,3

	Case 1	Case 2	Case 3
Estimated annual generation (MWh/year)	1111	1115	1117
Losses between module and inverter (%)	0.07	0.58	0.24
Losses between inverter and transformer (%)	0.82	0.04	0.05
Losses between transformer and meter (%)	0.00	0.00	0.03
Total losses (%)	0.89	0.62	0.32

The case 1 presents a way of execution of the solar system in which the inverters would be below the modules fixed to the metallic structures and the transformer close to the next connection. This case increases the distance from the low voltage conductor, carrying current from each inverter at low voltage, thus increasing losses.

The case 2 executes the system in order to install inverters and transformer close to the measurement point, this system shows that the maximum use of the solar cable is made, which works with direct current, improving the losses in relation to case 1.

The case 3 was used to find the optimal positioning of the components with the genetic algorithm, the program locates inverters and transformer at the same point, being necessary to include a physical and safe distance. This shows that it is better to transmit power over long distance using medium voltage versus alternating current and direct current of modules.

As shown in Table 13, it can be seen that in case 3 compared to case 1 there was a reduction in percentage losses from 0.89% to 0.32%, representing a reduction of approximately 60%. Likewise, case 2 compared to case 3, showed a reduction in total losses from 0.62% to 0.32%, a reduction of approximately 55%.

The need to supply the customer's electricity is 1110 MWh per year, so all installation cases would meet the factory's demand, but case 3 can be more efficient producing 6 MWh more than case 1 and 2 MWh a more than case 2.

A photovoltaic system has a minimum operating life of 25 years according to the module manufacturer's data sheet, disregarding module degradation in the first year and subsequent years, evaluating only the gains produced, case 1, case 2 and case 3 will produce 27,775MWh, 27,875MWh, 27,925MWh, respectively. Case 3 obtains an energy gain of 150 MWh in relation to case 1 and 50 MWh in relation to case 2.

These losses considering small, medium and large systems consider a significant savings in a 25-year investment scenario and reflected in the decrease in the return on investment of solar plants.

3.2 Discussion.

This article showed the importance of computing intelligence to solve optimization problems using computational methods, these methods are widely used in all areas of engineering and adding value to renewable energy.

The method proposed to develop this article was the genetic algorithm, this method is widely used in external redistribution of loads to serve cities and in the study of wind power plants, thus, the method used was chosen to carry out the internal redistribution of solar ground mounted power plants, showing the novelty within this study in using the genetic algorithm to reduce electrical losses in cabling of solar farms, validating its redistribution and internal configuration.

The study presented an analysis of the engineering project for the service of a factory that will be served through the connection of the electric company's network, the article showed that two project execution layout used, their relative losses and the estimated generation, later, applying the genetic algorithm to carry out the redistribution and calculate the proposed new electrical losses. The result of the new form of execution, evidenced in case 3, showed an improvement of 60% between the studied case, and consequently a generation of 6MWh year more and 150MWh in relation to 25 years of useful life.

The important point of this study is that it creates and addresses its analysis through Excel spreadsheet system tools to use the genetic algorithm implemented in Solver's Evolutionary Mode, a spreadsheet is released to use in other plants around the world, which any reader will be able to replicate the methodology applied to analyze other solar plants with the necessary adaptation.

All this work was validated using Pvsyst, a program specialized in sizing, configuration and simulation of photovoltaic systems, guaranteeing the accuracy of the used results shown in this paper to proof about to the losses and simulations of generations found.

This work does not show an analysis for photovoltaic systems carried out in three dimensions, which reflect systems executed on roofs, being a limitation of the same. And being the target for a future study, in the same way, the work only focuses on electrical losses, being also the target of the next study to carry out the genetic algorithm to optimize the size of the conductors and an analysis of the values involved in relation to the cost as well, as variables.

In any case, this study shows practical advances such as modifying an existing layout in order to maximize energy production by minimizing electrical losses when considering existing premises, such as conductor size and the considered distance.

The genetic algorithm in a computational space for large systems can bring problems due to the computational effort, that is, it may take hours or days for the system to converge to a satisfactory result. What could help in the treatment of the result would be a block analysis, as it would reduce the computational effort.

IV. CONCLUSIONS

The growth of solar energy is enormous on a world stage with the installation of systems even in homes to large plants to supply electricity to cities, with clean energy being the most cited today. With this, challenges and innovations arise for the implementation of technology, from more powerful modules, ways to optimize solar production and reduce losses, thus bringing more and more improvements to the systems as a whole.

Combining computational intelligence with renewable energies, especially solar energy, becomes challenging and innovative, as a photovoltaic system has several variables that impact its entire production chain, whether the location chosen for the plant, choice of technology correct for the solar modules and components, as well as the sizing to guarantee the security of the system, and its reduction of losses.

This paper use genetic algorithm to find the best solution to place the inverter and transformer in free zone of a solar project, this can be very challenging to do just with experience of the designer because you can have n row of panels instalations among the site, so to find the correct place to put the alternate current component increase the effiency of the all system, increasing the annual energy production as shown.

This work aimed to minimize the losses in the cabling of a photovoltaic system, treating this problem to be solved by the optimization using the genetic algorithm, supported in the evolutionary mode implemented in the spreadsheet tool in Excel with the Solver, with this, we can prove some points.

1- A problem faced by many solar energy designers can be solved by a genetic algorithm to vary the placement of electrical components and find the ideal solution within the terrain to be installed in a solar plant.

2- It was demonstrated during the study that the choice of layout configuration of a solar farm directly influences the efficiency of the system, which may bring greater or lesser losses.

3- According to the result shown in Table 13 and demonstrated the positioning layout in Figure 3 shows that medium voltage transmission is better for system efficiency.

Several studies with optimization are applied in renewable energy to improve and increase the sustainability of the planet, this study performs a work in two dimensions coordinate axes X,Y of each type of component of solar plants installed on the ground, but future work of the academy can be carried out to adapt to the X,Y,Z coordinates that reflect the installation of solar systems on roofs and bring optimization also related to cable sizing, and added to the cost of purchasing conductors, the cost of cabling degradation and finding of optimally, the best positioning considering not only the loss factor, but also the investment factors of the entire arrangement and construction, and completing with another optimization methods too to make comparations with genetic algorithm solution.

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